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ATTENTIONAL DEMANDS AND EFFECTS OF EXTENDED PRACTICE IN A ONE-FINGER KEY-PRESSING TASK

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SUMMARY

This paper attempts to define mechanisms for producing rapid movement sequences early and late in practice. Twelve subjects completed eight hours of practice on a task in which a response consisted of a sequence of three key presses, the first two of which were fixed over all trials while the third was stimulus dependent. In some dual task blocks a low or a high pitched tone was presented during various phases of sequence production in order to determine attentional demands of sequence preparation and execution. The results show that attentional resources are required for preparing but not for executing the sequence. Extended practice was found to gradually improve anticipation of response production but no evidence was found for qualitative changes in the way the sequences were produced as suggested by notions of distributed programming and response integration. Secondary task interference reduced only little with practice. The present results provide further evidence for the notion that a general principle of producing movement sequences underlies one and multi-finger key press sequences. In contrast to assumptions of multiple resource theories about parallel processing the results suggest that when more than one task require attention at the same time limited attentional resources are and remain a major bottle-neck for dual task performance. This is evidence for a single channel model of task performance.

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Aandacht en effecten van oefening in een sequentiële toetsdruktaak

W.B. Verwey

SAMENVATTING

In dit rapport wordt een poging gedaan mechanismen te vinden welke gebruikt worden voor de uitvoering van snelle bewegingssequenties voor en na oefening. Twaalf proefpersonen oefenden gedurende acht uur een taak waarin een respons bestond uit een sequentie van drie toetsdrukken, de eerste twee waren altijd dezelfde terwijl de derde stimulus-afhankelijk was. In enkele dubbeltaak blokken werd een hoge of lage toon gepresenteerd gedurende verschillende fasen van uitvoering van de sequentie om zo vast te kunnen stellen in welke mate aandacht nodig was voor preparatie en executie van de sequentie. De resultaten laten zien dat preparatie van de bewegingssequentie aandacht vergt maar executie niet. Uitgebreide oefening verbeterde wel de mate waarin geanticipeerd werd op uitvoering van de taak maar er werd geen bewijs gevonden dat de sequentie op een kwalitatief andere wijze uitgevoerd werd zoals gesuggereerd door noties als "distributed programming" en "response integration". Dubbeltaak interferentie nam slechts weinig af met training. De huidige resultaten geven wel evidentie voor het idee dat er een algemeen principe is voor de uitvoering van bewegingssequenties met zowel één als meerdere vingers. In tegenstelling tot aannamen van "Multiple Resource" theorieën over parallelle processen in dubbeltaak situaties suggereren de resultaten dat indien meerdere taken tegelijkertijd aandacht vragen dit een belangrijke bottle-neck is en blijft. Dit ondersteunt het idee van een "single-channel" model van taakuitvoering.

1. INTRODUCTION

During recent years there has been a growing interest in mechanisms underlying acquisition of perceptual-motor skills and the extent of attentional involvement (e.g., Logan, 1988; Rabbitt, 1989). Several mechanisms have been proposed like improved anticipation, distributed programming and response integration. However, the circumstances under which they occur and their mutual relationships are unclear. Also, the role of attention is not clear especially since motor behavior and attention are traditionally separate areas of research. The present paper is an initial attempt to find under which conditions these mechanisms develop and to what extent they interact.

It has been traditionally assumed that preparation of overt actions require attentional resources but that faster actions do not demand attention once the action has started (Carr, 1979; Neumann, 1987; Schmidt, 1972). It is also generally assumed that in sequences of relatively short rapid actions preparation involves complete preprogramming of the sequence (e.g. Donkelaar & Franks, 1991; Kornbrot, 1989; Rosenbaum et al., 1984; Sternberg et al., 1978). So far the question whether preparation and execution of rapid movement sequences require attentional resources has not been addressed. Yet, together the earlier notions suggest that preprogramming a sequence of movements requires attentional resources and execution of the sequence does not. Absence of attentional demands during the actual execution of a response sequence would allow attention to be devoted to other tasks and would therefore enable efficient performance in multi-task situations.

One interesting issue concerns the role of practice. It has been stated that with practice attentional demands reduce considerably because representations of subsequent responses integrate into one larger unit (Brown & Carr, 1989; Carr, 1984; Hulstijn & Van Galen, 1988; Logan, 1980; Verwey, 1990a, 1990b). Integration would reduce the time for preparing and executing responses within an integrated sequence (Brown & Carr, 1989; Cohen et al., 1990) and would reduce interference with a secondary task because of reduced attentional requirements (Brown & Carr, 1989; Carr, 1984; Logan, 1980). Since integration would reduce attentional requirements, it may also allow programming of forthcoming responses to occur during execution of earlier responses, that is distributed programming (e.g. Garcia-Colera & Semjen, 1988; Verwey, 1990a). Evidence for distributed programming has, for example, been found in writing (e.g. Hulstijn & Van Galen, 1983) and typing (Rosenbaum et al., 1987; Salthouse, 1986). Distributed programming has been found to develop during practice but may also be utilized without much practice (e.g. Garcia-Colera & Semjen, 1988; Rosenbaum et al., 1987). This study tests the possibility that attentional demands of response preparation and execution (i.e. production) reduce with practice, for example because of response integration, so that distributed programming can be used.

Another mechanism that may develop with practice is response anticipation. Response anticipation refers to the possibility that with practice, one learns to execute all preparatory processes that do not depend on the imperative stimulus before the stimulus is being presented. The Hierarchical Editor model (HED, Rosenbaum et al., 1984), which describes how rapid key pressing sequences are produced, relies heavily on this assumption. The model, however, does not say to what extent practice is required to attain full anticipation. Note that distributed programming and response anticipation do not necessarily exclude each other: when preparation for earlier responses precedes the imperative signal, later responses can still be programmed during execution of the earlier responses.

In the present study, an attempt is made to stimulate the development of distributed programming by only making the third (last) response stimulus dependent. The earlier two responses are fixed across trials. This allows the development of anticipatory processing and, possibly, of integration of the first and second response. In order to get a view on attentional demands during sequence production, a secondary task is introduced in some conditions. This task involves the presentation of tones during several phases of sequence production. Response slowing as caused by these tones is taken as indicator for momentary attentional demands and practice with this task is deliberately kept limited. Task interference at the peripheral level is prevented by using different modalities and using immediate responses in one task only. The notion is tested that attentional resources are required for preparing a sequence of movements but not for its execution. High attentional involvement in sequence preparation and low involvement in execution would be indicated by a clear slowing of the time to initiate the first response and a relative insensitivity of later responses to the secondary task.

The present study also attempts to determine whether mechanisms like anticipation, distributed programming, and response integration develop with extensive practice. Anticipation would result in very short sequence initiation times. Distributed programming is assumed to be only possible once attentional demands of either preparation or execution are low so that these two can occur concurrently. Distributed programming would result in elimination of the complexity effect in the sequence initiation time (e.g. Henry & Rogers, 1960; Fischman & Lim, 1991), as caused by manipulating variability of the third response in the sequence, and by an increase of interresponse times caused by concurrent planning processes (Klapp & Wyatt, 1976; Verwey, 1990a). Finally, response integration would reduce attentional demands of sequence production and would reduce interresponse times between responses that follow each other consistently (Brown & Carr, 1989). In the present experiment the first and second response are expected to integrate since these are practiced in a consistent order and, hence, the time to initiate the second response would reduce with practice.

Earlier, Ulrich et al. (1990) found evidence for the notion that there is a general principle of producing movement sequences with different fingers on both hands - as used by Rosenbaum et al. (1984) to develop the HED model - and successive key presses done with the same finger. The present study is a nice possibility to further test the generality of the HED model in successive key pressing with one finger. The HED model assumes that a motor program is constructed before a key pressing sequence is executed. To set up the program each step in the program has to be edited in a step by step fashion. To minimize the duration of the edit pass during the choice RT interval, the edit pass proceeds up to the first uncertain response element before the choice signal is presented. After presentation of the choice signal the edit pass is continued and, once finished, the execution pass starts. In the frame of these assumptions the time to execute the first response is determined by the number of response elements in the sequence minus the number of certain initial responses. For the present experiment this implies that the first response would take longer when the third response is stimulus determined than when it is fixed. According to the HED model the interresponse times are determined by the number of steps required to step through the program. In case an element is uncertain until signal presentation an additional step is required and a longer interresponse times precedes execution of that element. In the present situation this means that the time taken to execute the third response is longer when it is stimulus dependent than when it is fixed (cf. Rosenbaum et al., 1984 exp. 3).

2 METHOD

2.1 Subjects

Twelve right-handed students (7 females and 5 males) of Utrecht University served as subjects. They all received Dfl. 180 for participation. In addition, the four subjects that had the least sequence errors, responded fastest and did best on tone counting received a bonus of Dfl. 45.

2.2 Tasks

Each trial started with the presentation of an outline of a square in the center of the screen. The square functioned as a warning stimulus and remained visible for 500 ms. After the outline had been erased, one stimulus letter, from a set of four uppercase letters (W, X, S, F), appeared at the location corresponding to the center of the square. The stimulus required a sequence of three responses and it remained on until the last key of the response sequence had been pressed. The response sequence consisted of three keystrokes on the numerical keypad of a normal AT-like keyboard with the right index finger. The first and second keystroke were always the 3 and 5 keys (Fig. 1). The third key was contingent upon the letter presented. Presentation of W required pressing the 2 key. Likewise, presentation of X, S, or F required pressing the 4, 6, or 8 key.

The variable sequence condition consisted of sessions with four subsequent blocks of 60 experimental trials in which the stimulus was randomly chosen from the set of four possible stimuli. In contrast, the sessions in the fixed sequence condition consisted of four separate blocks of 60 trials with only one of the four stimuli in each block. Prior to each fixed block subjects were informed about the stimulus to expect.

A

7	$8_{(3)}$	9
$4_{(3)}$	$5_{(2)}$	$6_{(3)}$
1	$2_{(3)}$	$3_{(1)}$

B

•	F	•
X	•	S
•	W	•

Fig. 1 Layout of the numerical keypad on the AT keyboard (A) and the mapping of stimuli to the third response (B).

Another variation was single vs. dual task. In the dual conditions subjects had the additional task of counting the number of target tones. High (2000 Hz) or low pitched tones (200 Hz) were presented at irregular intervals during a block of trials. Whether target tones were either the low or high pitched ones was randomly determined for each block and indicated to the subject prior to the start of a block. Tones were presented before or during sequence execution. During a trial tones could be presented at either one of five positions or not at all. The positions are depicted in Fig. 2. Each of these six possibilities had an equal probability (about .17).

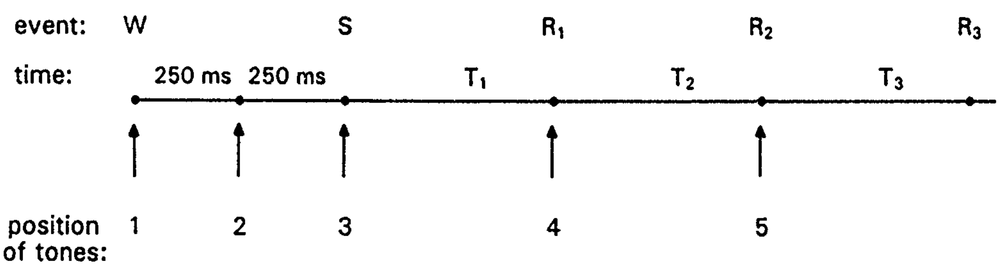

Fig. 2 Order of the warning stimulus (W), imperative stimulus (S) and responses 1 to 3 (R_1-R_3). In the dual task condition a tone was presented with equal probability at either one of the indicated moments (position 1-5) or not at all.

2.3 Design and analysis

Mean intervals between the imperative signal and the onset of the first key press R_1 (referred to as T_1), and the interresponse intervals between the first and second key press (R_1 and R_2: T_2), and the second and third key press (R_2 and R_3: T_3) were analyzed with a 2 x 2 x 6 x 4 x 12 design (fixed vs. variable sequence x single vs. dual task x tone position x day x subject)[1]. Numbers of errors were subjected to an inverse sine transformation and to an analysis with the design above. Finally, the deviation between number of target tones and number indicated by the subjects was divided by the total number of target tones and transformed by inverse sine before analysis with a 2 x 4 x 12 (fixed vs. variable sequence x day x subject) design.

2.4 Apparatus

The experiment was conducted on IBM AT compatible computers with NEC multisync monitors. Stimulus presentation and response collection were controlled through Micro Experimental Laboratory software (MEL - Schneider, 1988). The visual stimuli were presented in the center of the display screen. At a typical viewing distance of about 65 cm the warning square subtended a visual angle of approximately 1°. The stimulus letters subtended a visual angle of approximately 0.5°. Tones were presented on the computer speaker and were clearly audible. The keyboard had delays of about 10 ms for the response keys used. Average amount of timing inaccuracies reported by MEL were 3 ms per trial.

Subjects were simultaneously tested in seven dimly-lit sound-attenuated 2.4 x 2.5 x 2 m rooms in front of a table on which their keyboard was positioned. They were allowed to sit as preferred as long as their right index-finger rested on the first key before the start of a trial.

2.5 Procedure

Twelve subjects visited the Institute on four consecutive afternoons. On the first day, a written instruction was handed out which briefly introduced the tasks and the way the computer had to be controlled. Then, subjects received a training procedure in which they were further instructed and had about fifteen minutes training in order to master the stimulus-response mappings. In the training procedure one of the stimuli was randomly chosen and displayed and subjects were asked to press the appropriate key. After pressing a key, feedback was given and all stimulus-response mappings were displayed until the subject

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[1] "Tone position" in the single task condition was in fact a random number between and including one and six.

indicated that the next stimulus could be presented. For each correct response a counter corresponding to that button was decreased by one. All counters started at 15. When making an error, the counter was incremented by two. Only when all four counters were below zero, the training procedure was ended. This procedure ensured that subjects had a reasonable knowledge about the mapping of the stimulus on the third key during the experimental trials. During the training procedure the two tones were also presented on several occasions so that the subjects knew what to consider as low and high pitch. Subjects were instructed to rest their right index finger on the first key of the sequence (i.e., the "3") in the experimental trials.

After the training procedure subjects performed in a single task, variable session consisting of four blocks. This session was considered practice. Next, they performed in four experimental sessions that involved two fixed and two variable sequence sessions, one of each was a single task condition the other a dual task condition. The order of these sessions was balanced over subjects according to a Latin square. On day two to four, three single task, variable sequence training sessions were performed followed by, again, four balanced experimental sessions. So, subjects practiced much more in the variable condition than in the fixed condition and more in the single task than in the dual task condition.

During the experiment, a sequence of key presses was considered wrong when a incorrect key was pressed or the order was incorrect. In addition, when pressing the first key took more than 2000 ms or pressing the second and third key took more than 1500 ms each the sequence was considered wrong. In case of an error, subjects were informed about what kind of error they made after the third key had been depressed. Inter-trial times lasted about 1200 ms, the first 1000 of which were reserved for presentation of an error message in case this was required.

Following a block of 64 trials (4 initial dummy, 60 experimental trials) performance feedback was displayed in terms of the mean time between stimulus on-set and the moment of pressing the third key and in terms of the percentage error trials. When the mean time between stimulus on-set and pressing the third key exceeded 1000 ms an additional message stated that the subject was too slow. When the percentage of error trials exceeded 7 percent subjects were informed that they made too many errors. After completing a block of trials subjects indicated the number of target tones. Subsequently, the correct number of target tones was displayed. When subjects deviated more than 10 percent they were warned and urged to pay more attention to tone counting. The total number of warnings on sequence production and tone counting on day two to four was used to determine which four subjects received the bonus.

One group of six subjects worked for about 15 min. in one session and rested for the same period of time while the other group was tested. Each session included four blocks each lasting about three to four min. At the end of each block subjects got performance feedback, entered the number of target tones (when appropriate) and rested for 23 s. Then the next block of trials started with a short reminder about which stimuli could be expected and whether tones were to be counted and, if so, whether that was the low or high tone.

3 RESULTS

Mean reaction times were submitted to three separate analyses of variance: one for the time required to initiate the first response and two for the two inter-response times. In addition, proportion of deviation in counted target tones were subjected to an analysis of variance. Error rates were always less than 5 percent and will not be further discussed.

Main effects of fixed vs. variable response sequence were found on T_1 and T_3 [$F(1,11)=34.4$, $p<.001$; $F(1,11)=19.0$, $p<.01$] but not on T_2 (Fig. 3). Day of testing also showed main effects on T_1 and T_3 [$F(3,33)=83.6$, $p<.001$, $F(3.33)=6.72$, $p<.01$] but not on T_2 [$F(3,33)=0.42$]. T_1, pooled over conditions, was found to diminish with 92, 41, and 6 ms between successive days. T_3 reduced with 23, 2, and 7 ms. Fixed vs. variable response sequence and day of testing did not interact.

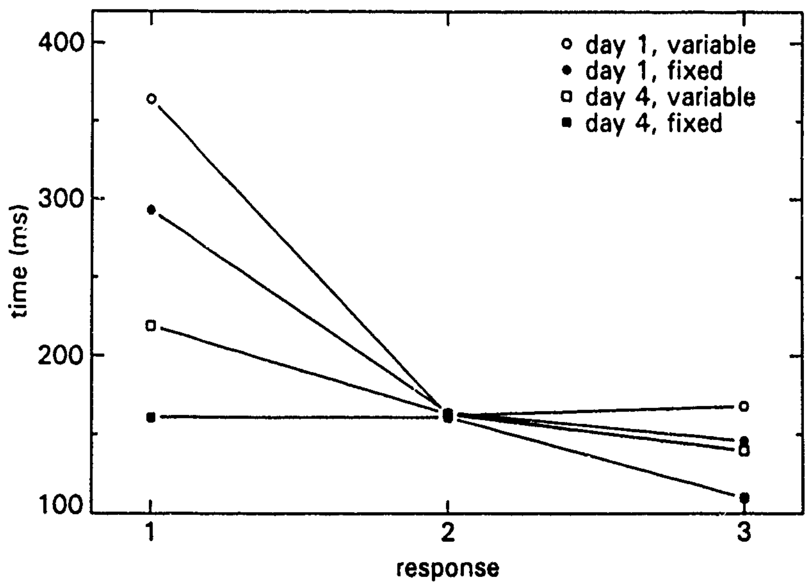

Fig. 3 Stimulus to R_1 time (indicated as response 1) and inter-response times between R_1 and R_2 (response 2) and between R_2 and R_3 (response 3) as a function of fixed vs. variable sequence and day of testing.

Simultaneous tone counting in the dual task condition lengthened all response intervals: T_1 by 46 ms [$F(1,11)=24.4$, $p<.001$]; T_2 by 11 ms [$F(1,11)=13.5$,

$p<.01$]; T_3 by 13 ms [$F(1,11)=28.6$, $p<.001$]. However, the effect on T_1 also depended on the moment of presentation as indicated by a single vs. dual task x tone position interaction [$F(5,55)=12.54$, $p<.001$]. As shown in Fig. 4, T_1 increased with tone position up to R_1 execution. Newman-Keuls comparisons showed that all T_1s in the dual task condition differed significantly from those in the single task condition ($p<.05$). T_1s related to tones following R_1 (position 4, 5, and 6) were not significantly different from each other. This is trivial since these tones followed execution of the first response and could therefore no longer affect T_1. All other comparisons of T_1 in the dual task condition were significant ($p<.05$).

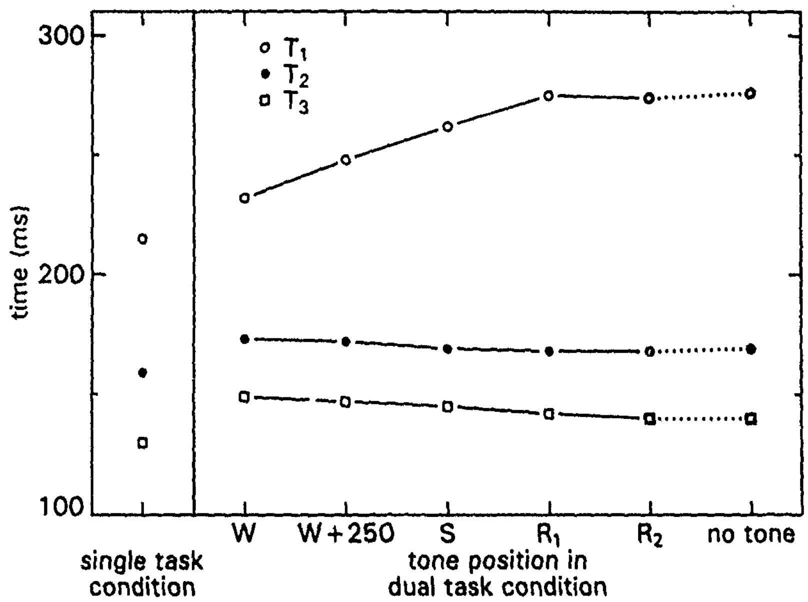

Fig. 4 T_1, T_2, and T_3 as a function of tone position in the single and dual task conditions pooled over days and fixed and variable conditions.

A fixed vs. variable sequence x single vs. dual task x tone position interaction [$F(5,55)=3.86$, $p<.01$] on T_3 indicated that T_3 was an almost linearly decreasing function of tone position in the variable sequence whereas it was insensitive to tone position in the fixed condition. When a tone was presented at the same time as the warning signal T_3 was about 20 ms slower than when the tone was presented following R_2 or when the tone was not presented at all - tones following R_2 onset and no tone at all yielded equal T_3s.

Together, the relations as depicted in Fig. 4 were relatively stable over practice in the fixed and variable conditions. A general downward shift of T_1 and T_3 occurred with practice: T_2 did not decrease at all.

Finally, the only effect of practice on task interference was found in tone counting performance. Tone counting improved with practice as evidenced by a main effect of day of testing [$F(3,33)=8.32$, $p<.001$]. The difference between the correct number of target tones and the numbers entered by the subjects amounted 5.9%, 2.0%, 1.5%, 1.5% on day one to four. No other effects on tone counting performance were found.

4 DISCUSSION

This study aimed at studying possible mechanisms contributing to the production of movement sequences before and after extensive practice and the role of attention during various phases of practice. The data suggest that throughout the experiment key pressing sequences were completely preprogrammed before execution of the first response. The role of practice appears to have been limited to the development of anticipation, that is to shifting signal-independent preparatory processes in time so that they occurred before presentation of the imperative stimulus. Attentional resources were practically exclusively required for preparation and not for execution. The expectation that a tone would be presented led to anticipatory allocation of attentional resources to both response preparation and tone processing implying that keeping a task organized requires substantial attention which did not reduce with practice. Applicability of the HED model to pressing separate keys with one finger suggests that a general principle of producing movement sequences underlies one and multi-finger key press sequences.

Earlier notions that preparation of choice reactions require attention whereas response execution does not (Neumann, 1987; Schmidt, 1972) together with the notion that in sequences of rapid movements programming completely precedes execution (Rosenbaum et al., 1984) led to the suggestion that attention is required during preparation but not during sequence execution. The results provide evidence for this notion because the latency to the first response clearly increased when the secondary task had to be performed concurrently in contrast to the interresponse times which were hardly affected by the secondary task. The finding that this occurred without much practice suggests that sequence execution does not require attention at any stage of practice.

Further examination of the data revealed something that had not been expected. The original expectation was that the time to initiate the first response would only increase when the tone would be presented shortly before execution of the first response. Conform this expectation, early tone presentation showed only limited increase of sequence initiation time suggesting timely reallocation of attentional resources. Yet, in contrast to expectations, the time to initiate the first response was longest when the tone had yet to come. In other words, the subjective expectation for a tone interfered more than when the tone was actually presented shortly before execution of the first response. Actually, this finding replicates earlier findings in a stimulus matching paradigm where temporally unpredictable probe tones were presented (Posner & Klein, 1973). This phenomenon gives rise to the interesting notion that dual task interference was not so much caused by concurrent information processing per se, but, instead by prior allocation of attentional resources to different tasks - no matter whether concurrent processing did indeed take place or not. It can be regarded further evidence that maintaining processing structures and keeping a task organized requires attention (Carr, 1979; Logan, 1978).

The slight but persistent slowing of the second and third response in the tone counting condition appears a general effect of concurrent processing. Possibly, response execution requires a small amount of attentional resources or, alternatively, the presence of a secondary task activates the use of a central executive (McLeod, 1978; Noble et al., 1981). This effect was not found to change with practice.

In the present study the sequence production task was practiced for over eight hours in order to examine whether different ways of processing occur earlier or later in practice as a consequence of anticipation, distributed programming or integration. The finding that it took less time to initiate the first response after practice can be ascribed to increased anticipation. Given the presence of a fixed foreperiod of 500 ms in combination with advance knowledge of the first response this is not unexpected. Inspection of the raw data supports this: on day four, four out of the twelve subjects in the fixed sequence condition and one subject in the variable sequence condition were found to have a mean sequence initiation time below 100 ms while simple visual reaction times average between 185 and 200 ms (Luce, 1986). Apparently, with practice subjects learned to execute processes before presentation of the imperative stimulus. Note that in the present experiment sequence initiation time reduced clearly until day three indicating that it takes reasonable practice to make full use of anticipation.

Since no interaction was found between the effects of practice and fixed vs. variable sequence on the time to initiate the first element in the sequence, anticipation appears not to have depended on whether the third response was known in advance or not. Hence, anticipation in the variable as well as in the fixed condition must have concerned processes that were aspecific with regard to the third response. On the other hand, the finding that presentation of the tone before or during the warning interval had bigger repercussions for performance of the third response in the variable conditions than later presentation of the tone suggests that some preparation for the third response occurred before signal presentation even though the third response was not known at that time. This is consistent with the notion that sequence structures can be programmed in advance even if specific movement elements are still unknown (Verwey, 1990a, 1990b; Ziessler et al., 1990) but preparation of a still unknown response appears to require more attention than preparation of a specific response.

No evidence was found for distributed programming and response integration. Response integration was predicted to occur between the first and second response given their consistent order. The effects found were opposite to those predicted by response integration: no reduction of the time to initiate the second response but a reduction of the time to initiate the third response.

How, then, can it be explained that Brown and Carr (1989) did find reduced interresponse times in a sequential key pressing task? They found reduced interresponse times with practice in relatively long sequences (six key presses) in which the distance between the keys resulted in relatively long interresponse times (about 400 ms). Such long times have been found to promote separate programming of each key press in a sequence (Donkelaar & Frank, 1991; Garcia-Colera & Semjen, 1988). So, interresponse times in Brown and Carr's study may have involved response preparation as well as execution whereas in the present study all preparation had occurred before execution. Hence, it may well be that response integration does not affect so much execution processes but instead preparatory processes, for example, because a complete motor control program can be retrieved from memory and need not be programmed over and over again. Since in the present study preparation took place before initiation of the first response, any effect of integration on preparatory processes was obscured by co-occurrence of anticipation. Future studies should investigate the possibility that practice primarily reduces preparation time.

The possibility that distributed programming would develop with practice, possibly because of reduced attentional demands of response production with practice, was also investigated. As discussed before, attentional demands of response execution were already limited early in practice. Still, no proof was found that distributed programming developed. Distributed programming would have been indicated by clear attentional demands during sequence execution, by elimination of the complexity effect as caused by fixed and variable sequences and, possibly, by longer interresponse times. In fact, none of these effects were found and the complexity effect remained remarkably stable with practice. It may well be that distributed programming only occurs when response selection and programming have to be postponed because the sequence is too long to program as a whole (Garcia-Colera & Semjen, 1988; Rosenbaum et al., 1987), when the choice stimulus is presented after execution of earlier responses (Verwey, 1990a), or when the sequence is carried out slowly (Donkelaar & Franks, 1991). One thing the present results do make clear is that low attentional demands of executing responses are not a sufficient condition for distributed programming.

The pattern of response times confirm the predictions of the HED model (Rosenbaum et al., 1984) put forward in the introduction both early and late in practice. The data, therefore, are further support for the validity of the HED model for key pressing sequences with only one finger and indicate that a general principle of producing movement sequences underlies one finger and multi-finger key press sequences as suggested by Ulrich et al. (1990). Usage of a fixed foreperiod did not affect applicability of the HED model. Of course, further research should demonstrate whether this remains the case for more complicated sequences, as well.

It is interesting to recognize that the data support the notion that dual task interference is actually not eradicated when attention is required at the same time for two tasks even though very different modalities are used (Pashler, 1990). In other words, the present results support recent evidence for single-channel models of dual task performance (Gladstones et al., 1989; Pashler, 1990) and rejects applicability of multiple resource theories (Friedman & Polson, 1981; Wickens, 1984) when more than one task require attention. One reason that many studies did find strong reductions in dual task interference with practice (e.g., Allport et al., 1972; Brown & Carr, 1989) may be that those tasks gave ample opportunity to learn how and when to switch attention between tasks. Also, seemingly parallel processing may have resulted from the possibility to prepare abstract response features in separate output buffers in rapid succession (Fitzgerald et al. 1988; Tattersall & Broadbent, 1991) before the tasks were actually executed. Only when there is no possibility to sufficiently prepare responses to both tasks, interference becomes independent of whether the same or different output modalities are being used. This was found by Gladstones et al. (1989).

Future research should investigate the possibility that response integration affects sequence preparation instead of execution. Fischman and Lim (1991) stated that the degree of transfer of training to slightly different sequences may serve as indicator for response integration. This proposal deserves further attention.

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10. TITLE AND SUBTITLE

Attentional demands and effects of extended practice in a one-finger key-pressing task

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

This paper attempts to define mechanisms for producing rapid movement sequences early and late in practice. Twelve subjects completed eight hours of practice on a task in which a response consisted of a sequence of three key presses, the first two of which were fixed over all trials while the third was stimulus dependent. In some dual task blocks a low or a high pitched tone was presented during various phases of sequence production in order to determine attentional demands of sequence preparation and execution. The results show that attentional resources are required for preparing but not for executing the sequence. Extended practice was found to gradually improve anticipation of response production but no evidence was found for qualitative changes in the way the sequences were produced as suggested by notions of distributed programming and response integration. Secondary task interference reduced only little with practice. The present results provide further evidence for the notion that a general principle of producing movement sequences underlies one and multi-finger key press sequences. In contrast to assumptions of multiple resource theories about parallel processing the results suggest that when more than one task require attention at the same time limited attentional resources are and remain a major bottle-neck for dual task performance. This is evidence for a single channel model of task performance. (25)

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